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DREO TECHNICAL NOTE 82-12

WICKING ABILITY, WATER ABSORPTION, AND THERMAL RESISTANCE OF SEVERAL THERMAL UNDERGARMENT FABRICS

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Environmental Protection Section
Protective Sciences Division

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ABSTRACT

In response to a request from DCGEM eight different undergarment materials were evaluated to determine the properties of thermal resistance, the ability to wick, and to absorb water.

It is not possible from the tests performed to rate one undergarment sample as much better than the rest in all characteristics. One sample (a plain knit fabric of 100% polypropylene) exhibited the greatest ability to wick, and the greatest amount of water absorbed. The thermal resistance of all the undergarments is quite small as compared to an Arctic clothing assembly. Of the undergarments measured, a honeycomb knit of 100% cotton had a slightly higher thermal resistance.

The relative importance of these properties depends upon the environment, the characteristics of other components of the clothing ensemble and the tasks to be performed by the person wearing the garments.

RÉSUMÉ

Par suite d'une demande présentée par la DFGM, nous avons évalué huit différents tissus pour sous-vêtements afin d'en déterminer la résistance thermique ainsi que la capacité d'imbibition et d'absorption de l'eau.

Il n'est pas possible d'affirmer, à partir des tests effectués, que la qualité des échantillons est nettement supérieure à celle des autres par rapport à chacune des caractéristiques. C'est un tricot uni 100% polypropylène qui a présenté la plus grande capacité d'imbibition et d'absorption de l'eau. La résistance thermique de tous les sous-vêtements est assez faible comparativement à celle des vêtements de l'Arctique. Parmi les échantillons, le nid d'abeilles 100% coton avait une résistance thermique un peu plus élevéee.

L'importance relative de ces propriétés est fonction de l'environnement, des caractéristiques des autres pièces de l'habillement et des tâches que la personne portant le vêtement est appelée à remplir.

INTRODUCTION

Eight different protective undergarments were obtained from DCGEM. Their materials were tested in order to determine the properties of thermal resistance, ability to wick, and water absorption.

SAMPLES

Sample 1 - Green honeycomb knit of 100% cotton. Made by Penmans. Current CF underwear.

Sample 2 - Green knit fabric of 100% combed cotton. The knit resembles an elongated honeycomb. Made in Canada by Sportsman.

Sample 3 - Fleece-like knit fabric of 85% (minimum) thermolactyl chlorofibre. Made in England by Damart Thermolactyl. Label has warning to avoid heat of any kind.

Sample 4 - Plain tight knit fabric of 85% thermolactyl chlorofibre. Made in England by Damart Thermolactyl.

Sample 5 - Honeycomb knit fabric of 85% thermolactyl chlorofibre, 15% acrylic. Made in England by Damart Thermolactyl.

Sample 6 - Plain loose knit fabric of 100% polypropylene. Fabric is called Knitwick. Made in Canada by Superskins.

Sample 7 - Two-layer fabric. The outer layer of 65% cotton, 25% wool, 10% nylon; inner layer of 100% cotton. Made by Duofold.

Sample 8 - Fishnet fabric of 50% Fortrel polyester, 50% cotton. Made by Dorbin Duofold.

Manufacturers listed are garment manufacturers who may or may not have produced the fabric.

METHOD

The thickness and weight of each fabric was determined after conditioning at 65% relative humidity and 21°C.

Thermal resistance measurements were made on a Rapid K Thermal Conductivity Instrument. Heat flow was measured at the predetermined sample thicknesses when the sample was placed between two plates. The top plate was set at 25°C, the lower plate at 35°C.

Conditioned samples (65% RH, 21°C) of the undergarments were weighed to determine a dry weight. Each was then placed on the surface of a distilled water bath and allowed to submerge for periods of 1 minute, 5 minutes and 15 minutes; being allowed to drip drain at room conditions for 1 minute prior to reweighing. The percentage weight gain was then calculated.

To represent the effect of friction and pressure on water absorption of the undergarments by the skin during wearing, conditioned samples were submerged in a distilled water bath, removed and squeezed by hand. They were again placed on the surface of the water for 1 minute. The samples were allowed to drip drain for 1 minute at room conditions prior to reweighing. Again, the percentage weight gain was calculated.

The ability of the samples to wick was measured both vertically and horizontally in a conditioned atmosphere of 65% RH and 21°C. For both conditions, a graduated scale of 1 cm intervals was marked on 3 x 15 cm strips of fabric using a felt pen with water-soluble ink. As soon as the mark began to run the time was recorded. The ink was not visible on the two green samples; in these cases the graduated scale was marked by running a line of yellow stitching across the sample. There was sufficient darkening to the fabric when wet to be able to monitor the wetted length. Each test was run for a maximum of 20 minutes. The distance the water travelled, as a function of time was recorded.

The assembly for the vertical wick test, which is similar to that described by de Boer (1), is shown in Figure 1. The lower end of the sample was immersed in a distilled water bath.

The horizontal wick apparatus is shown in Figure 2. A metal ruler rested on the top of two 250 ml beakers, one full of distilled water. The sample lay on the ruler with one end immersed in the beaker of water.

The results from three runs were averaged and plotted.

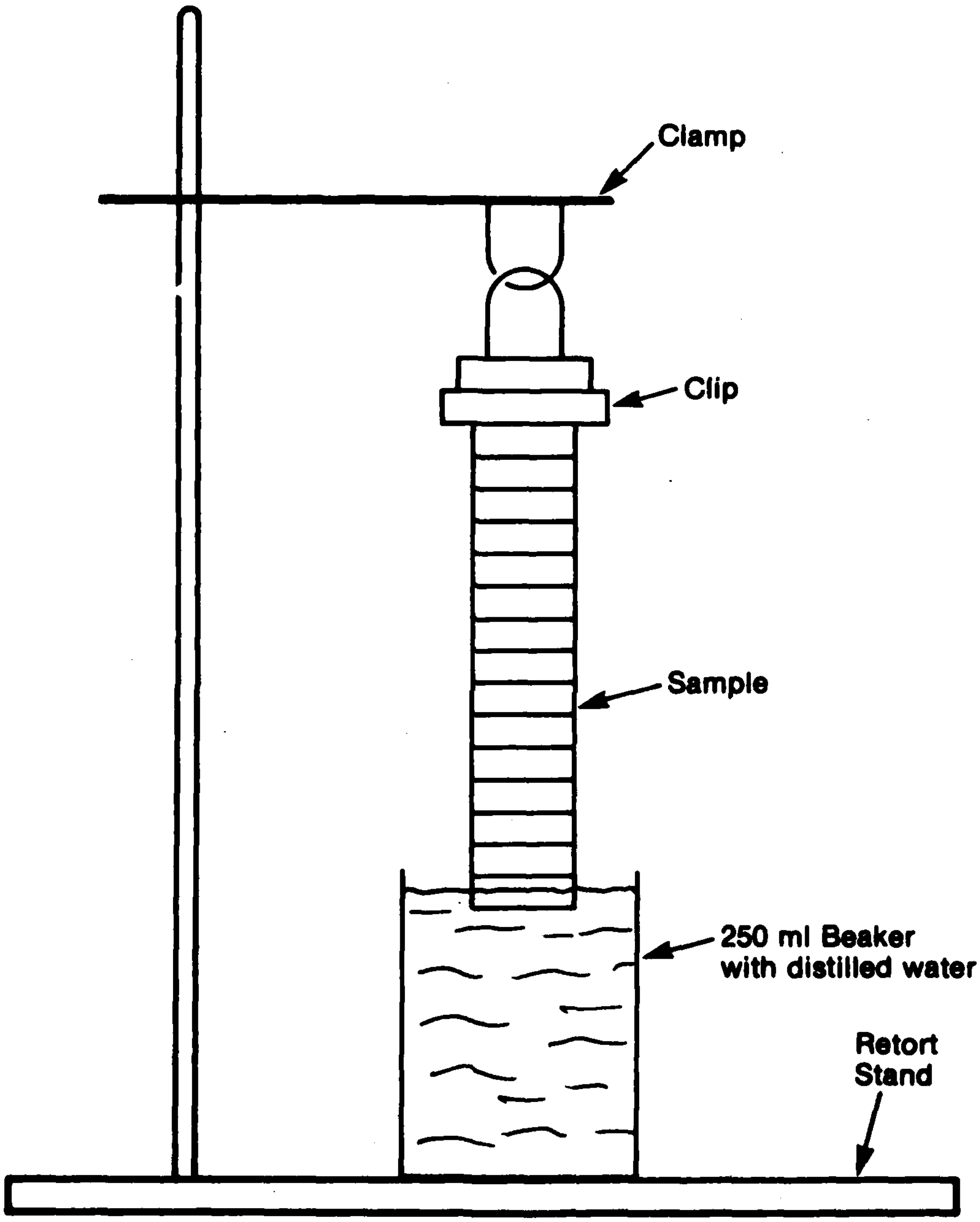

Figure 1: Vertical Wicking Apparatus (similar to that of de Boer (1)).

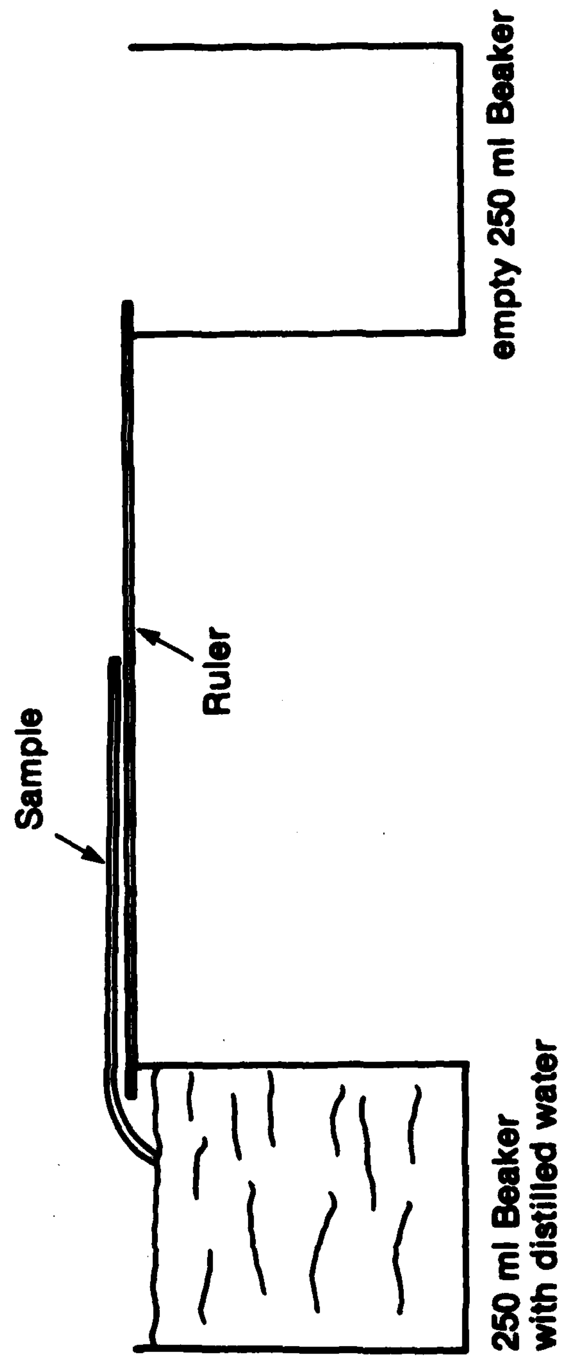

Figure 2: Horizontal Wicking Apparatus.

RESULTS AND DISCUSSION

The results of the thermal resistance tests are shown in Table 1.

The thermal resistance of each of the undergarment samples tested is quite small as compared to the overall thermal resistance of the current Canadian Forces Arctic clothing assembly. This assembly has a resistance of about 0.45 m^2 K/W, which is approximately ten times the resistance of underwear measured. Thus the addition of thermal underwear to a clothing system intended for use in the Arctic adds little extra warmth or protection for the wearer, and the differences in intrinsic thermal resistance among these samples is insignificant. The thermal resistance provided by the undergarment also depends a great deal upon a layer of trapped air between it and the skin and therefore upon the fit of the garment.

Of the undergarments measured there is a general increase in thermal resistance as the thicknesses of the samples increased.

Error may have resulted in the thermal resistance measurements taken, due to the fact that the Rapid-K is not intended to measure samples at the small thicknesses of these samples, nor the small thermal resistances.

The results of the wicking tests are illustrated in Figures 3 and 4. Samples 2 and 6 appear to have much better wicking ability than samples 3, 4, 5 or 8. Sample 7 did not wick any water during either the vertical or horizontal wicking trials. Sample 1 wicked water only to the 1 cm mark on both vertical and horizontal wicking trials after 20 minutes immersion. Therefore these two samples are not represented on the graphs.

During the vertical wicking tests, the height to which water rises up the fabric is determined by two factors. As the height of the column of water increases the pressure at its bottom increases. As a result, the rate at which water is forced into the fabric decreases. Also as the height of the column increases the area available for evaporation increases. The column of water will rise to a height at which the liquid flow into the fabric balances the evaporation rate.

In the horizontal wicking tests, the height of the column of water does not change. The final length of the wetted area depends only upon the rate of evaporation.

The two types of experiments give different information and different errors. However the two tests rank the wicking ability of the various fabrics in the same order.

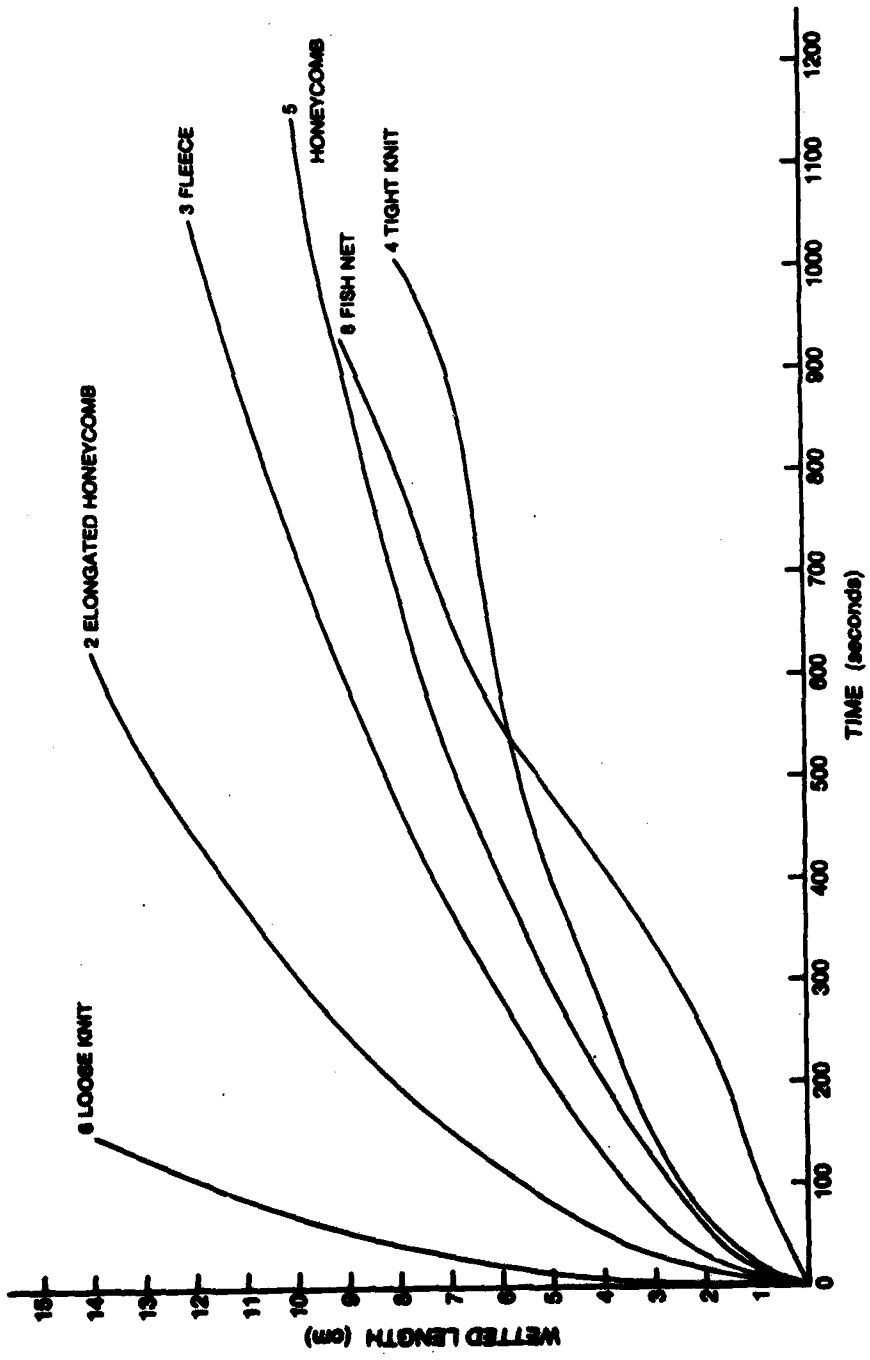

Figure 3: Wetted Length Versus Time from Horizontal Wicking Trials.

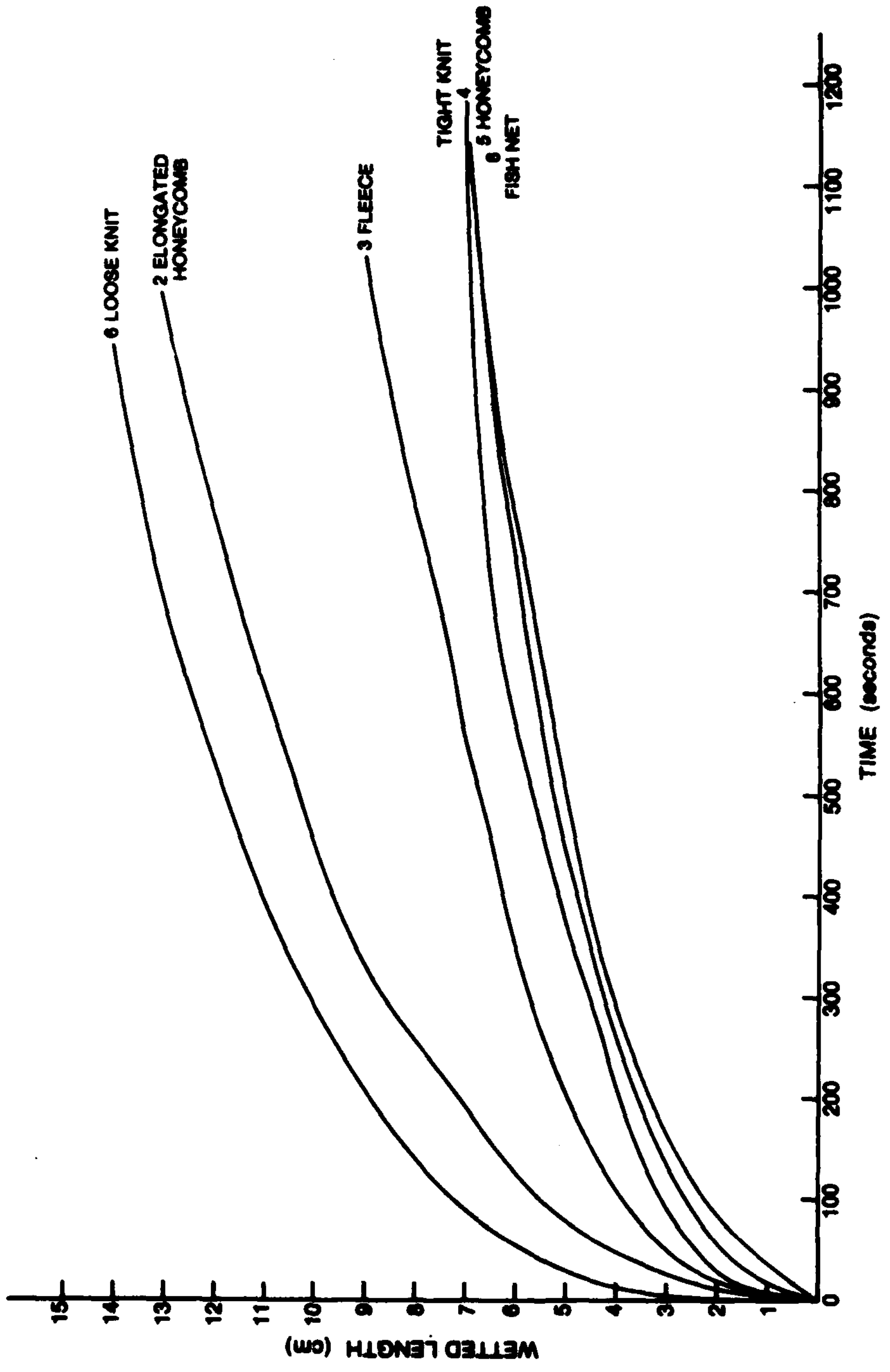

Figure 4: Wetted Length Versus Time from Vertical Wicking Trials.

TABLE 1

Summary of Thickness, Weight, Water Absorption and Thermal Resistance Results

Sample	Thickness (mm)	Weight (g/m^2)	Water Absorbed (% dry weight) 1 min	Water Absorbed (% dry weight) 5 min	Water Absorbed (% dry weight) 15 min	Water Absorbed (squeezed) (% dry weight) 1 min	Resistance (m^2k/W)
1 Green honeycomb 100% cotton	2.57 ± 0.09	313	62 ± 5	377 ± 17	406 ± 3	359 ± 0	0.049
2 Elongated honeycomb 100% cotton	1.98 ± 0.01	340	345 ± 3	353 ± 5	365 ± 6	342 ± 3	0.035
3 Fleece 85% Thermoactyl chlorofibre	1.63 ± 0.02	329	263 ± 4	265 ± 4	271 ± 4	271 ± 1	0.039
4 Tight knit 85% Thermoactyl chlorofibre	0.98 ± 0.01	239	189 ± 2	188 ± 3	197 ± 0	189 ± 1	0.027
5 Honeycomb 85% Thermoactyl chlorofibre	1.70 ± 0.02	230	213 ± 2	204 ± 5	219 ± 4	205 ± 3	0.043
6 Loose knit 100% Polypropylene	1.54 ± 0.05	173	349 ± 9	356 ± 6	357 ± 10	342 ± 4	0.030
7 Two layer Outer: 65% cotton, 25% wool 10% nylon Inner: 100% cotton	1.11 ± 0.02	208	42 ± 10	61 ± 9	72 ± 5	243 ± 10	0.024
8 Fish net 50% cotton 50% Polyester	2.25 ± 0.04	206	229 ± 15	251 ± 1	262 ± 2	253 ± 4	0.040

It has been stated by Cassie and Baxter (2) that there is difficulty in wetting rough surfaces because of their large apparent contact angles. When fabric samples are immersed in water the pores between the fibres and yarns trap air because of large apparent contact angles of fibres. Samples 1 and 7 have a rough surface due to the cotton fibres, and are therefore difficult to wet. When samples are squeezed, the air pockets are broken down, and the water is able to come in contact with more of the fibres, thus increasing water absorption. Friction and pressure exerted by the skin on the undergarments during wearing, has the effect of breaking down the air pockets, thus increasing water absorption and possibly the wicking ability of the undergarments.

Wettability is also partly dependent on the ratio: distance between the yarns to the diameter of the yarn. If the ratio is large (fibres of a small diameter and large pores), as is the case with sample 6, water will pass right through the structure at contact (2).

It may be argued, but it is by no means certain, that wicking and water absorption are both desirable properties of undergarment fabrics. If the sweat produced evaporates at the skin, it will pass as water vapour through the fabric (3). As a result the pores of the fabric remain free, and the heat insulation value of the air within the pores is maintained (3). The ability of the fabric to wick up water from the perspiring skin, and to spread it over the fibre surface will enable liquid-assisted heat and water vapour transmission to take place (4). Heat loss in this manner will balance the additional heat produced by the wearer when performing light to moderate work (5). If there is profuse perspiration, the garment may become saturated, the fabric pores becoming water filled. This may reduce the insulating ability of the garment so much that it may no longer be adequate to protect the wearer once he stops working; and the body heat being produced drops. As a garment becomes wet or damp, the thermal balance may be preserved, but there may be a feeling of clamminess, and the wet clothing may cling and cause chaffing of the skin (5).

An undergarment fabric that does not absorb perspiration also has disadvantages. If there is a great deal of perspiration, it may run down the body, and there again may be a feeling of clamminess (6).

CONCLUSIONS

It is difficult, from the test performed, to say that one of the undergarment samples is ideal, or better than the rest. If high wicking ability is desired as the major characteristic of the undergarment, sample 6 would be the best. This sample also absorbs a great deal of water quite rapidly. There is no experimental data that suggest that these are desired

characteristics. Compared to the thermal resistance of the current Canadian Forces Arctic clothing assembly (0.45 m^2 K/W), that of each underwear sample is quite small. Sample 1 has a slightly higher thermal resistance than the other underwear samples.

ACKNOWLEDGEMENT

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